SEMI-ANNUAL REPORT ON THE PROGRAM OF
RESEARCH IN SPACE-RELATED SCIENCES ESTABLISHED
AT THE UNIVERSITY OF FLORIDA UNDER NASA RESEARCH
GRANT NsG 542

Submitted by the University of Florida

Gainesville, Florida

for the period

1 November 1964 - 30 April 1965

Office of the Graduate School
May, 1965

TABLE OF CONTENTS

INTRODUCTION

The following reports have been submitted by the individual principal investigators under the NASA Institutional Grant for Research in Space-Related Sciences at the University of Florida. These reports cover the period 1 November 1964 through 30 April 1965, and constitute the required semi-annual report under the subject grant, NsG 542. It should be noted that two of the projects active during this period, A07 and A21, have now received other funding, while a third project, A04, was retired by the Steering Committee. Thus, vacancies are being created which will permit rotation of additional projects into the Institutional Grant program.

PROJECT A01:   STUDY OF THE 20 MC/SIGNAL FROM THE S-66 SATELLITE

1. <u>Department</u>:   Physics and Astronomy

2. <u>Principal Investigator</u>:   A. G. Smith

3. <u>Background</u>:

Since 1956 the Department of Physics and Astronomy has been engaged in monitoring and analyzing the decameter-wavelength radiation from the planet Jupiter. This program has resulted in more than 40 publications in books and journals, and a total of 21 graduate theses and dissertations. At present 12 graduate students and 5 undergraduate assistants are engaged in this work, together with 3 faculty members and a post-doctoral research associate.

The Jovian signals are received in the form of short bursts or pulses that are usually of the order of one second in duration. Occasionally the bursts have durations in the millisecond range, or even less commonly in the range of 10 or more seconds. Comparisons of records made simultaneously in Florida and at a field station 7040 kilometers away in Chile show that the short-term features of the records are almost completely uncorrelated. It is naturally of the greatest interest to discover whether the burst structure is Jovian in origin, or whether it originates in the terrestrial ionosphere or the interplanetary medium. The objective of this project is to compare the Jovian signals with the known signal from the S-66 (BE-B) satellite in order to identify ionospheric influences on the structure of the records.

4. <u>Progress</u>:

Identical 20 Mc/sec yagi antennae have been erected on steerable mountings for simultaneous observation of Jupiter and the satellite. Observations of S-66 (BE-B) began on October 10, following the launching of the satellite, and have been made regularly since that date. Signals from the antennae are amplified by Collins 75 S1 receivers and recorded on a Brush Mark II dual-channel high speed pen recorder. Jupiter is monitored each night during the time it is above the horizon as a part of the

Observatory's regular program. When a satellite pass occurs (typically 2 or 3 times during a normal Jupiter watch), it is the observer's responsibility to drop other experiments and to monitor the satellite pass. Since the Jovian radiation is highly sporadic, 20 Mc/sec Jovian signals are received during only a small percentage of suitable satellite passes. Nevertheless, simultaneous signals have now been recorded a number of times when the planet and the satellite were at appulse, and it is believed that some preliminary statistical conclusions can be drawn. In order to quantize the observations, scintillation character indices have been assigned to each signal for each pass. Present indications are that the satellite index and the Jovian index show virtually no correlation, leading to the conclusion that the Jovian burst structure is not an ionospheric scintillation. This conclusion will of course be strengthened as more data are accumulated. It can be remarked that this finding is in accord with J. N. Douglas' belief that the burst structure is caused by drifting interplanetary plasma clouds.

Advantage has been taken of the observations to investigate the effect on satellite scintillations of altitude, latitude, direction, and time of day. The findings are in general in agreement with expectations based on the work of other observers. However, it has been noted that our data show strikingly greater scintillation for south-to-north passes than for those in the opposite sense. The data are being restudied to see if this curious effect can be attributed to diuirnal or other influences before concluding that it is indeed a purely directional phenomenon. The satellite records of course show marked Faraday rotation, which can be used to measure the electron content of the ionosphere. The values range from 0.3×10^{16} to 70×10^{16} electrons in a column of 1 m^2 cross section, although most runs give values between 1×10^{16} and 10×10^{16}. Since the launching of the second beacon satellite, BE-C, on April 29, regular observations of it have been added to the program.

5. <u>Results</u>:

The following papers based in whole or in part on this work have been presented:

(a) W. F. Block, A. G. Smith, and T. D. Carr, "Frequency Dependence of Ionospheric Faraday Rotation from Radio Spectrum of the Planet Jupiter." Fla. Academy of Sciences, March, 1965.

W. F. Block, W. A. Morton, and A. G. Smith, "A Comparison of Ionospheric Modifications of the Radio Signal from an Artificial Satellite with Jupiter's Radio Burst Morphology." Fla. Academy of Sciences, March, 1965.

(b) A. G. Smith, "Morphology of Jupiter's Decametric Radio Sources," NATO Advanced Study Institute on Planetary and Stellar Magnetism. University of Newcastle Upon Tyne, Newcastle Upon Tyne, England, April, 1965.

A. G. Smith will present a paper, "Influence of the Terrestrial

Environment on the Temporal and Statistical Characteristics of Jovian Decametric Radiation", devoted extensively to these studies at the Second Symposium on Radio Astronomical and Satellite Studies of the Atmosphere, Air Force Cambridge Research Laboratory, Boston, October, 1965.

Dr. W. F. Block's doctoral dissertation, "Spectrum and Origin of the Jovian Radio Burst Structure", University of Florida, April, 1965, contained portions of these studies.

Mr. W. A. Morton's M. S. thesis, "Ionospheric Scintillation of the 20 Mc/sec Signals from the BE-B and BE-C Beacon Satellites", is devoted to these studies.

A journal article related to these studies is currently under preparation by Block and Smith.

6. Budget:

	Expended to Date	To be Expended
Salaries	$3,771.00	$ 109.00
Expenses	87.76	132.24
TOTALS	$3,858.76	$ 241.24

PROJECT A02: PLANETARY OBSERVATIONS WITH THE ARECIBO 1000-FOOT RADIO TELESCOPE

1. Department: Physics and Astronomy

2. Principal Investigator: T. D. Carr

3. Objectives:

(a) To observe Jupiter at 430 Mc/s with the 1000-foot radio telescope at the Arecibo Ionospheric Observatory, Arecibo, Puerto Rico.

(b) To make observations of other sources with the Arecibo radio telescope.

(c) To observe Jupiter at 6.3 Mc/s from a deep valley near the Arecibo Ionospheric Observatory.

4. Results:

Mr. Frank Tiberi, a University of Florida graduate student, made a second series of 430 Mc/s Jupiter observations at Arecibo between January 4 and February 12, 1965. Approximately 130 drift curves of Jupiter and 100 of a control source were made in this series. The analysis of these measurements indicated a more pronounced variation of intensity with System III longitude than had been found from the first series (in 1964). The longitudes of the

intensity maxima had also changed during the period of approximately one year between the two series. This longitude shift could be explained if the actual rotation period were 4.7 (± 3.1) seconds longer than the System III period; however, other possible explanations have not yet been ruled out. The increased variation of intensity with longitude in the second series apparently indicates that some significant change in Jupiter's environment must have taken place since the first series of measurements. Mr. Tiberi is continuing the theoretical work in which he is attempting to account for the observed effects.

Samuel Gulkis, another University of Florida graduate student, has continued his work at Arecibo (Mr. Gulkis is a NASA Trainee). This work has consisted of two parts, as follows: (a) Prediction of lunar occultations of discrete radio sources, observations of occultations at 3 frequencies with the 1000-foot radio telescope, and analysis of the data, all under the general direction of Professors Marshall Cohen and Cyril Hazard of Cornell University, (b) Completion of his Ph.D. dissertation under the supervision of the principal investigator.

Gulkis developed a computer program for calculating the topocentric and geocentric coordinates of the moon, which are essential for the accurate prediction of occultations. He organized and assisted in a routine search for radio sources which would later be occulted by the moon; occultations of approximately 10 of these were subsequently observed. Many other sources were observed and cataloged, but were not observed in occultation. Gulkis more recently began the development of a computer program for calculating source position and brightness distribution directly from occultation measurements.

Dr. Gulkis' Ph.D. dissertation is entitled "A Theoretical Model for the Emission of the Decametric Radiation from Jupiter". It is based on work done at the University of Florida, and to a smaller extent at the Arecibo Ionospheric Observatory. Dr. Gulkis received the Ph.D. in April 1965; his support by NASA terminated on this date. He is now permanently employed by Cornell University at the Arecibo Ionospheric Observatory.

As reported previously, a 6.3 Mc/s polarimeter was constructed at Arecibo in August, 1964, by the principal investigator and Mr. Jorge May, a University of Florida graduate student. Jupiter observations with this instrument were made for two weeks with an operator in attendance, and for several months unattended. The recordings have recently been analyzed. It was found that despite the shielding provided by the deep valley in which the antenna was situated, the severity of static from local thunderstorms prevented the attaining of useful results when the equipment was operated automatically. However, good data were obtained when an operator was present to identify the Jupiter noise bursts as they occurred. Results obtained from the few good records lead to the interesting conclusions that the effect of the ionosphere upon the intensity and polarization of the Jupiter noise bursts at the lower frequencies can be greater than had been suspected previously, and that the bursts are of longer duration than they are at higher frequencies.

5. <u>Papers Presented Relating to these Results</u>:

(a) "Observations of Jupiter at 430 Mc/s in Puerto Rico", by Frank Tiberi and T. D. Carr, Florida Academy of Sciences, Tallahassee, Florida, March 12, 1965.

(b) "Observations of Jupiter at 6.3 Mc/s in Puerto Rico", by Jorge May and T. D. Carr, Florida Academy of Sciences, Tallahassee, Florida, March 12, 1965.

(c) "Asymmetrical Stop Zones in Jupiter's Magnetosphere", by Samuel Gulkis and T. D. Carr, Florida Academy of Sciences, Tallahassee, Florida, March 12, 1965.

(d) "Recent Results of the University of Florida Group", by T. D. Carr, NASA Jupiter - Burst Observers Conference, NASA Goddard Space Flight Center, Greenbelt, Maryland, April 26, 1965.

Also, forthcoming papers are to be presented by J. A. Roberts of Australia and by T. D. Carr at the Symposium on Planetary Atmospheres and Surfaces as Deduced from Radio Observations, Dorado Beach, Puerto Rico, May 24-27, 1965.

6. <u>Budget</u>:

	<u>Salaries</u>	<u>Expense</u>	<u>Totals</u>	<u>Percent</u>
Budgeted	5,700.00	3,000.00	8,700.00	
Expended through April 30	1,800.00	1,738.96	3,538.96	41%
Anticipated Expenditures by November 1	3,900.00	1,261.04	5,161.04	59%

PROJECT A03: INVESTIGATION OF THE LOW-FREQUENCY EXTREME OF THE JOVIAN RADIO SPECTRUM

1. <u>Department</u>: Physics and Astronomy

2. <u>Principal Investigator</u>: A. G. Smith

   <u>Co-Investigator</u>: C. N. Olsson

3. <u>Background</u>:

     As detailed in earlier reports, University of Florida studies[1] have shown that a major portion of the Jovian decametric energy probably lies at extremely low frequencies. Furthermore, important changes in the decametric source structure seem to occur at frequenceis of 10 Mc/s and downward.[2]

It is clear that any serious attempt to develop theoretical models of the emission process must rely heavily on low-frequency data. It appears that Saturn may also be a decametric emitter, [2, 3] and there are theoretical reasons for believing that its energy may be concentrated at frequencies still lower than those of Jupiter.

Unfortunately, the region below 15 Mc/s is one of great experimental difficulty because of natural and man-made interference and ionospheric opacity. The present project was designed to investigate the advantages to be derived by placing the antennae in a site that is extremely well shielded and remote from artificial interference. Using funds from the Institutional Grant, a field station has been established in a deep mountain valley in the Chilean Andes, inland from the coastal city of LaSerena. Initial equipment at the station included an 8-element, 5 Mc/s interferometer with a baseline of 3,000 feet and an 18 Mc/s steerable yagi antenna. Observations began during July of 1964.

4. Progress During the Report Period:

Additions to the equipment included a 12 Mc/s polarimeter, since recent University of Florida results have indicated that low-frequency polarization data are of great importance in establishing models of the Jovian magnetic field, whereas measurements at the higher frequencies give little information.[4] Also, 12 Mc/s data are needed to establish the drift in longitude of the decametric sources between 10 and 15 Mc/s, which is at present ambiguous.[2] Professor Olsson is currently in Chile erecting a 10 Mc/s interferometer using yagis as the elements. Professor Olsson and Dr. W. F. Block will direct observations during the current summer, the station having been manned by Chilean personnel for the winter months.

Final reduction of observations of the 1964 apparition of Jupiter must await return of the records to the United States (the apparition will end with conjunction with the sun on May 30). A preliminary reduction has been made of the 18 Mc/s data for the first two months of observations, and an excellent histogram of source structure was obtained,[5] which is unusual for such a brief period. The probability of receiving signals was 0.8 when the principal source was on the central meridian; this probability is nearly double that usually obtained at other sites, testifying to the superb listening conditions at the new station. During the coming summer the 5 and 10 Mc/s interferometers will be used in an intensive effort to settle the question of radiation from Saturn, which will be well-placed for observation during this period.

The report period saw the near-completion of a prototype of a flight-model radiometer for making Jovian observations from a satellite at frequencies of 4, 2, 1, and 0.5 Mc/s. This development was undertaken under NASA Contract NASR-176. A follow-up proposal to construct flight hardware for the OGO-G satellite has now been submitted to NASA. When the flight experiment takes place, it is expected that ground-based data, especially those from the low-frequency station developed under Project AO3, will be of the utmost importance in properly identifying the signals received by the satellite. With this in mind, partial support of the station has been requested as a logical cost of the flight experiment.

5. <u>Budget</u>:

	Expended to Date	To be Expended
Salaries	$ 7,960.00	$ 6,680.00
Expenses	6,774.81	3,225.19
Capital Outlay	2,840.99	219.01
TOTAL	$17,575.80	$10,124.20

6. <u>References</u>:

1. T. D. Carr, G. W. Brown, A. G. Smith, C. S. Higgins, H. Bollhagen, J. May, and J. Levy. "Spectral Distribution of the Decametric Radiation from Jupiter in 1961". Astrophysical J.<u>140</u>, 778-795, August, 1964.

2. A. G. Smith, G. R. Lebo, N. F. Six, Jr., T. D. Carr, H. Bollhagen, J. May, J. Levy, "Decameter-Wavelength Observations of Jupiter: The Apparitions of 1961 and 1962". Astrophysical J.<u>141</u>, 457-477, 1965.

3. T. D. Carr, A. G. Smith, H. Bollhagen, N. F. Six, and N. E. Chatterton. "Recent Decameter-Wavelength Observations of Jupiter, Saturn and Venus". Astrophysical J.<u>134</u>, 105-125, July, 1961.

4. T. D. Carr, S. Gulkis, A. G. Smith, and H. Bollhagen. "Circularly Polarized Components of the Decameter Radiation from Jupiter." American Astronomical S. Meeting, Lexington, Kentucky; March, 1965. Abstract to be published in Astronomical Journal.

5. R. Hayward. "Decameter-Wavelength Radio Source Drift and Related Studies of the Planet Jupiter". University of Florida Master's thesis, April, 1965.

PROJECT A04:   STUDY OF PLASTIC SHEETS FOR USE IN ASTRONOMY

1. <u>Department</u>: Aerospace Engineering

2. <u>Principal Investigator</u>: David T. Williams

3. <u>Background</u>:

This project has been devoted to investigating the possibilities of utilizing a stretched sheet of metallized mylar as a large astronomical mirror for lunar or space use. A major effort has been devoted to developing a method of fabricating the precision metal drum over which the mylar is to be stretched. Additional study has been directed at the properties of the mylar film itself.

4. Current Status:

    In November of 1964 the University of Florida NASA Steering Committee,
after analyzing the report of the principal investigator, came to the con-
clusion that the probability of success was too small to warrant the expend-
iture of further funds from the Institutional Grant. A sum of $1,600 was
allocated to permit orderly phasing out of the project, although the Depart-
ment of Aerospace Engineering indicated that it might make further funds
available from its own resources. The principal investigator is currently
on leave at the Joint Institute for Laboratory Astrophysics at the University
of Colorado. Upon his return in October a final technical report on
Project A04 will be submitted.

PROJECT A05:   A STUDY OF NUCLEAR PARAMETERS OF ASTROPHYSICAL INTEREST

1. Department: Physics and Astronomy

2. Principal Investigator: F. E. Dunnam

3. Progress to Date:

    Most activities to date have been devoted to development and check-out
of data-collecting and data-handling apparatus, along with the preliminary
runs of the central item of equipment, the new 4-MeV Van de Graaff accelerator.
As stated in earlier reports, the purpose of these experiments is to clarify
critical parameters in a number of nuclear reactions which are of interest
to astrophysicists; neutron radiative capture reactions and alpha-induced
reactions are among those mentioned. The high beam current available from
the accelerator makes it ideal for studying reactions of low cross-section.
Since our last report, the following has been accomplished:

    P. N. Carlton, R. E. Daniel, and W. A. Bruton have designed and con-
structed an apparatus for determining angular distributions of nuclear reaction
products, particularly gamma rays (the outgoing energy carrier in the radiative
capture reactions mentioned above). The apparatus will become one of the
beam lines of the Van de Graaff, and requires only some vacuum system com-
ponents to be complete, although it is currently under test with an auxilliary
vacuum system. It features a remotely controlled, moveble counter which can
be placed at any desired angle with respect to the target under study;
after the data are taken it can be moved to a new position without the
operator entering the target room.

    J. Butler, W. A. Bruton, and M. Swisdak have spent considerable time
in perfecting target-making procedures. Very thin targets are needed in
many of the planned experiments, and the technique for making them is
quite critical. An apparatus for the controlled evaporation of thin films
is now in operation, and thin targets of magnesium and lithium have been
made successfully (and repeatedly).

    With respect to the Van de Graaff accelerator, it has recently been

rendered more useful to our experimental group with the addition of two important items. An optical transit has been installed for beam alignment which promises to save considerable time in setting up beam lines. The addition of a large magnetic quadrupole lens to the beam system will aid us most of all, however. Heretofore, we have had to depend on beam stops or apertures to make the beam small enough to strike a well-defined target area some distance from the machine. The full beam can now be concentrated on a spot of a few millimeters diameter with the new lens. Equipment is on hand for modifying the accelerator's ion source for use with helium (both isotopes 3 and 4), making these beams available in addition to the protons now in use. This will give us the alpha-particle beam needed for our next experiment.

The recent appointment of R. J. Stillwell as a technician for our group, as well as that of R. E. Daniel as a NASA Trainee, will give our group some welcome additional help.

4. Projected Next Steps:

The angular distribution apparatus will be used by Bruton, Carlton, Swisdak and Daniel to investigate several (α, γ) reactions, including those with Mg^{24}, Si^{28} and S^{32} as target nuclei. This operation will begin around June 14, when the accelerator will next be available to our group.

5. Budget:

	Budgeted	Expended	Percent Expended to Date	Percent to be Expended by 10/31/65
Salaries	$18,990.40	$11,996.63	63	37
Capital Outlay	10,774.48	2,561.88	24	76
Expense	6,362.24	5,238.48	82	14

PROJECT A06: STUDY OF MAGNETOFLUIDMECHANICS

1. **Department**: Aerospace Engineering

2. **Principal Investigator**: M. H. Clarkson

3. **Progress**:

Initial emphasis in this project has been placed on developing diagnostic techniques for rf-generated plasmas. The techniques are gradually being put to the task of obtaining a better understanding of rf-plasma generation and the characteristics of such plasmas. Since rf-plasmas are finding increasing application, both areas of endeavor are important. Project personnel are evenly divided between Aerospace Engineering and Electrical Engineering. Four doctoral candidates and five master's candidates are currently engaged on the project.

4. Probe results:

Measurements of electron temperatures have been made using a double‑floating probe of the Johnson and Malter type[1], some ten inches from the rf‑coil. This work formed the basis of a master's thesis[2] and the results for the so-called "glow" and "ring" discharges are shown in Figures 1 and 2.

In order to make similar measurements direcly in the discharge region, a larger discharge tube was constructed. At the same time a large electrode was placed in this tube to form one electrode of an asymmetrical double probe system. The use of an asymmetrical probe should allow the small electrode of the double probe to become electron saturated, which should allow a more accurate determination of number density. When the larger tube was put into operation it was found that neither the symmetrical nor asymmetrical double probes had the predicted characteristic curves. In particular, the asymmetrical double probe did not show the expected electron saturation even at large applied voltages. As the probes were then operating in a higher capacitive electric field, it was thought that this might have produced strong fields in the region of the probe, disturbing the normal sheath which forms at an electrode. Extensive shielding was constructed to minimize the capacitive electric fields and to insure that the fields inside the discharge would be primarily those induced by the solonoidal fields of the exciting coil. When this shielding was completed it was found that the probe characteristics again were similar to those predicted. With the shielding complete, however, it was found that the discharge would no longer initiate itself. External means were used to initiate the discharge, after which it would sustain itself.

At the present time theoretical calculations are being made in an effort to determine the field distribution in the discharge as a function of the complex conductivity. Solutions for the case of constant pure imaginary conductivity and constant pure real conductivity have been obtained.

Preparations are being made by a graduate student to determine the ion species in the plasma by means of an rf‑mass spectrometer.

5. Microwave Techniques and Field Measurements:

The slotted, four-foot-long, plasma-loaded wave-guide and traversing standing wave probe assembly described in the last report have been completed. Standing wave patterns have been measured and electron number densities determined in the range of 3×10^8 per ml in an argon plasma operating at 4 microns pressure. These measurements were made at microwave frequencies well above the plasma frequency, where little attenuation is experienced. A higher-power source will be used in the near future, and will allow measurements near the plasma frequency. It has been noted that the measurement technique is so sensitive that slight amplitude modulation of the 10 megacycle excitation field is detectable. Also, unexpected standing wave patterns have been observed with plasmas of certain densities. These results are being investigated.

FIG. 1 ELECTRON TEMPERATURE AS A FUNCTION OF CHAMBER PRESSURE FOR A COIL POTENTIAL OF 3500 VOLTS PEAK-TO-PEAK. THE CIRCLES REPRESENT THE SOLENOID CONFIGURATION AND THE SQUARES REPRESENT THE SHORTED COIL CONFIGURATION.
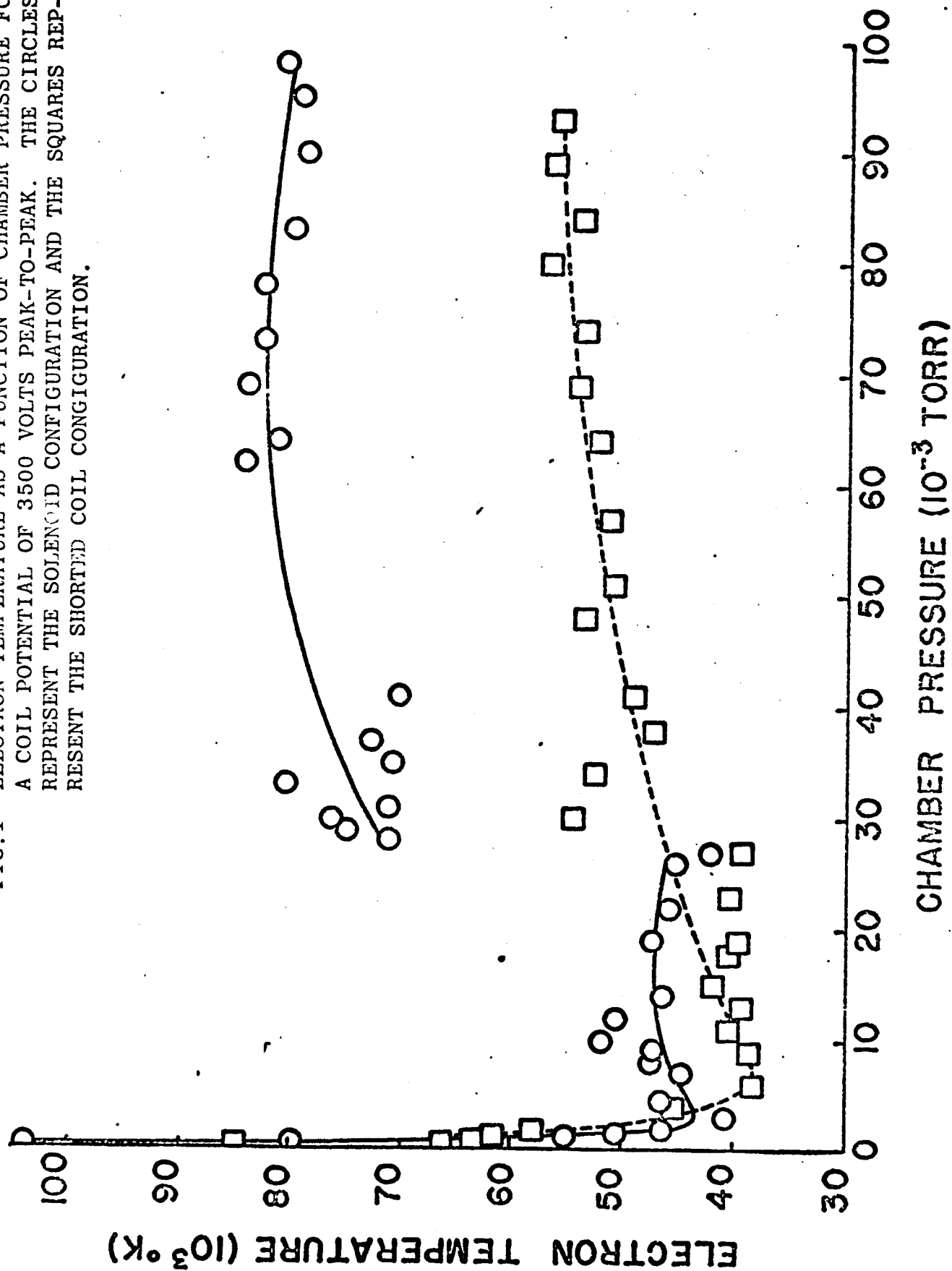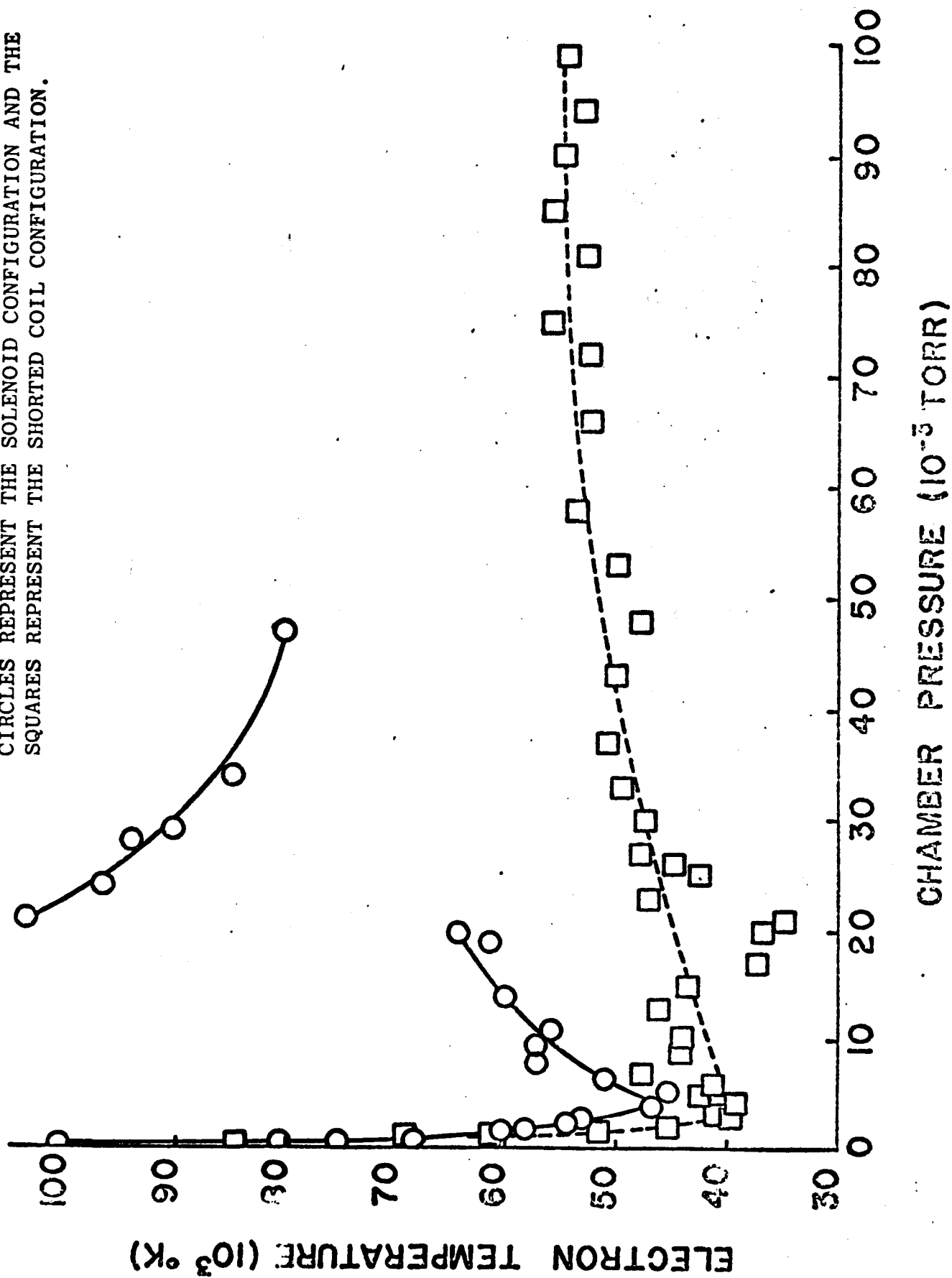
FIG. 2 ELECTRON TEMPERATURE AS A FUNCTION OF CHAMBER PRESSURE FOR A COIL POTENTIAL OF 5000 VOLTS PEAK-TO-PEAK. THE CIRCLES REPRESENT THE SOLENOID CONFIGURATION AND THE SQUARES REPRESENT THE SHORTED COIL CONFIGURATION.

As a check on the microwave technique, a floating double probe is being used to measure the electron termperature and density distribution in the plasma-loaded waveguide. Preliminary measurements appear quite successful and indicate an increasing number density as the center of the discharge is approached. A complete survey of the plasma is planned, including radial and axial distributions. This program will form the basis of a master's thesis.

Another master's candidate is investigating ways of measuring the electric field intensity produced by the excitation coil. The field distributions outside and inside the plasmas are of interest. One of the problems basic to the measurement is the electrical isolation needed to "float" the sensor so that it does not alter the field distribution. The approach under study uses a very small incandescent bulb powered from the electric field via two small conducting plates acting as a capacitor. The light produced is "piped" to a photo-detector through a small fiber-optic bundle which provides the electrical isolation. The necessary components have been assembled and preliminary tests are under way.

A satisfactory prototype of a magnetic field probe has been constructed and calibrated. Fixtures are being devised to allow sensing of the excitation field distribution within the slotted waveguide.

6. Thermal Plasmas:

Measurements of radial temperature distribution in an rf-plasma at atmospheric pressure are being performed using two independent methods: one method utilizes a heat transfer probe and the other a spectrometer.

Calibration of the spectrometer is expected to be completed in the next few weeks. The task at that time will be to make checks of optical thicknesses. Olsen[3] has tabulated several excited argon lines, each of which will be checked for optical thickness. Based on this work, from 3 to 5 lines will be chosen to form the basis of the experimental temperature determination. Utilizing several lines, the assumption of local thermodynamic equilibrium will also be checked.

7. Budget:

NASA Project A06 expenditures as of April 30, 1965:

Salaries	$21,786.71
Expense	1,627.64
Capital Outlay	4,442.18

The rate of expenditure is essentially on schedule; it is predicted that the remaining funds will be exhausted prior to November 1, 1965.

8. <u>References</u>:

1. E. O. Johnson and L. Malter, "A Floating Double Probe Method for Measurements in Gas Discharges," Phys. Rev., Vol. 80 No. 1.

2. R. E. Field, "An Experimental Study of Electron Temperatures in an RF Plasma," Master's Thesis, University of Florida, 1964.

3. Optical Spectroscopic Measurements of High Temperatures, P. J. Dickerman, The University of Chicago Press, 1961, "Plasma-Jet Temperature Measurement," W. J. Pearce, p. 125. See Olsen's tabulated data in appendix.

PROJECT A07: ELECTRIC BOUNDARY LAYERS

1. <u>Department</u>: Aerospace Engineering

2. <u>Principal Investigator</u>: Knox Millsaps

3. <u>Progress</u>:

This progress report is for the quarter 1 November 1964 through 31 January 1965, since the sponsorship for the project was transferred to the Air Force Office of Scientific Research upon the receipt of a two-year grant on 19 January 1965.

In brief, the major aim of this research task is to develop the hydrodynamic use of the electric boundary layer which exists at the interface between electrolytic solutions and a solid body that carries a charge. The dynamical movement of the solution produces a so-called streaming potential, and it is hoped that changes in the streaming potential can be used to ascertain designated changes in fluid velocity profiles. The first application which is being attempted is the experimental determination of the transition from laminar to turbulent flow in pipes. The outstanding improvement in experimental technique would be the complete absence of disturbing sensors in the flows.

Due to the sensitivity to environment of certain parameters such as viscosity, charge leakage, etc., it was necessary to design, construct and calibrate a laboratory with controlled humidity and controlled temperatures of $\pm 0.75^\circ$F over a 4 minute cycle; this has now been completed. Additionally, it was necessary to have conductivity water for use in the experiment, and water with a specific conductivity of 4.8×10^6 ohm cm is now being produced at a rate of 2 liters/hour. The construction of matched, calibrated, reversible calomel electrodes is still under way; however, intermediately useful silver silver-chloride electrodes have been fabricated and are being continuously and successfully used.

The reported research was done by two graduate students, one of whom is a NASA trainee, and by four undergraduate assistants.

4. Budget:

Expenditures to date:

Salaries $ 6,147.74

Expense   1,600.72   There is no projected
                                            expenditure.
Capital Outlay   2,158.03

    TOTAL $ 9,906.49

PROJECT A08:   STUDY OF THE BEHAVIOR OF INFLATABLE STRUCTURES

1. Department: Engineering Science and Mechanics

2. Principal Investigator: W. A. Nash

3. Progress:

     A nonlinear, finite-deflection theory for an air-mat shallow shell
has been derived through application of the principle of minimum potential
energy. Thermal effects have been included; nonuniformity of the total
shell thickness has been assumed. On the basis of an order-of-magnitude
analysis, the governing equations have been simplified and reduced to a
total of five equations; these equations have been, in turn, reduced to
four in number in the cases of static studies or the study of transverse
vibrations. For a shell with constant total thickness, further simpli-
fications have been carried out and the governing equations have been
reduced to a total of three equations. These equations are in terms of
the reduced displacement and stress functions, and they have the following
forms:

$$2h_f \left[\phi_{,yy} (Z_{,xx} - w_{,xx}) - 2\phi_{,xy} (Z_{,xy} - w_{,xy}) \right.$$

$$\left. + \phi_{,xx} (Z_{,yy} - w_{,yy}) \right] - ph \nabla^2 (w + \psi)$$

$$+ \tilde{\rho}\, \ddot{w} = q_w \tag{1}$$

$$\mathcal{L}_1[\phi] = (A_{11}A_{22} - A_{21}A_{12})\left[(w_{,xy}^2 - w_{,xx}w_{,yy})\right.$$

$$+ (Z_{,xx}w_{,yy} - 2Z_{,xy}w_{,xy} + Z_{,yy}w_{,xx})$$

$$\left. - \left(\alpha_{11}\frac{\partial^2\Omega}{\partial y^2} + \alpha_{22}\frac{\partial^2\Omega}{\partial x^2}\right)\right] \tag{2}$$

and

$$\mathcal{L}_2\left[\left(\frac{h^2}{4}\tilde{\rho}_f\frac{\partial^2}{\partial t^2} + ph\right)\psi + phw\right]$$

$$= hh_f(A_{11}A_{22} - A_{12}A_{21})\left(\alpha_{22}\frac{\partial^2}{\partial x^2} + \alpha_{11}\frac{\partial^2}{\partial y^2}\right)\nabla^2\omega \tag{3}$$

where

$$\mathcal{L}_1[\ ] \triangleq A_{11}\frac{\partial^4}{\partial x^4} + \left[\frac{(A_{11}A_{22} - A_{12}A_{21})}{A_{33}} - (A_{12} + A_{21})\right]\frac{\partial^4}{\partial x^2\partial y^2}$$

$$+ A_{22}\frac{\partial^4}{\partial y^4} \tag{4}$$

$$\mathcal{L}_2[\ ] \triangleq A_{21}\frac{\partial^4}{\partial x^4} + \left[\frac{(A_{11}A_{22} - A_{12}A_{21})}{A_{33}} - (A_{11} + A_{22})\right]\frac{\partial^4}{\partial x^2\partial y^2}$$

$$+ A_{12}\frac{\partial^4}{\partial y^4} \tag{5}$$

which are reducible to the two-dimensional biharmonic operator in the case of homogeneous isotropic face layers.

The unknown functions in the above equations are w, the average normal deflection of the upper and lower face layers; ϕ, a properly defined

stress function; and ψ , a two-dimensional continuous function, whose gradient gives the vector of the angles of rotation of the drop cords thus

$$\vec{\nabla} \psi = \alpha \vec{i} + \beta \vec{j} . \tag{6}$$

The adoption of the above simplification* in equation (6) is very common in theories of both isotropic homogeneous and sandwich plates and shallow shells [1,2]. It has also been introduced in a different version in the theory of inflatable structures[3]. Also, the two functions Ω and ω are the thermal gradients associated with the relevant temperature distributions on the upper and lower faces: α_{11} and α_{22} are the coefficients of thermal expansion for the orthotropic face material.

Several boundary and initial value problems are now under investigation. Solutions of these problems will serve as the applications of this theory.

4. Budget:

	Expenditures	Anticipated Expenditures
Salaries	$ 3,289.59	$ 1,211.00
Expense	15.00	155.00
Capital Outlay	-0-	167.00
TOTAL	$ 3,304.59	$1,153.00

5. References:

1. R. D. Mindlin, "Influence of Rotatory Inertia and Shear on Flexural Motions of Isotropic, Elastic Plates," Journal of Applied Mechanics, Vol. 18, No. 1, March, 1961, pp. 31-38.

2. E. I. Grigolyuk and P. P. Chulkov, "General Large-Deflection Theory of Elastic Sandwich Shallow Shells," Archiwum Mechaniki Stosowanej, Vol. XVI, No. 1, Warsaw, 1964, pp. 123-133.

3. A. F. Foerster, "Theoretical and Experimental Investigation of Metal Fabric Expandable Structures for Aerospace Applications," Aerospace Expendable Structures Conference Transactions, Dayton, Ohio, October, 1963, pp. 95-117.

---

* No approximation has been introduced by the adoption of equation (6) as long as the vector $= \alpha \vec{i} + \beta \vec{j}$ is irrotational.

PROJECT A09: STUDY OF THE FLUID FLOW IN FLEXIBLE TUBES IN LOW GRAVITATIONAL
FIELDS

1. Department: Engineering Science and Mechanics

2. Principal Investigator: J. Siekmann

3. Relative Equilibrium Configurations of a Rotating Finite Fluid Mass
   Under Capillary Forces Only, at the Axis of Another Rotating Liquid --
   An Extension of the Plateau - Rayleigh Problem

    The current need for an appropriate model simulating the effect of
apparent weightlessness on the relative equilibrium of incompressible fluids
under capillary forces only, has renewed interest in the early experiments
of Plateau dating back to the last century. These experiments were based
on the idea of immersing a mass of liquid in another of equal density and
immiscible with the first. The equilibrium configurations of the immersed
liquid would then be determined by capillary forces only, as is the case
during apparent weightlessness. The case in which the original sphere of
immersed liquid was made to rotate with a constant angular speed with the
help of a small disk at the end of a thin rotating shaft has been described
by Plateau. Analytical description of the observed changes in the relative
equilibrium of the interface is partially due to Beer and Neumann, who
pointed out the possibility of ring-formation as a certain critical speed
of rotation is reached.

    Rayleigh was the first to supply a numerical value of the non-dimen-
sional parameter--which alone governs the solution of the problem as long as
the immersed liquid intersects the axis of rotation--corresponding to this
critical speed. Further researches by Globa-Mikhailenko, Boussinesq and
Charrueau have added considerably to the theoretical background of the ori-
ginal experiments. More recently, Rosenthal and Dimaggio have essentially
rediscovered the early solution to the problem in the form of elliptic in-
tegrals for the case when the interface intersects the axis of rotation, but,
in addition, they have considered the effect of the surrounding liquid
assumed to rotate with the same speed as the immersed liquid of a different
density. When the interface ceases to intersect the axis of rotation, the
solution is governed by two parameters, and it can be expressed only in the
form of a hyperelliptic integral, rather than in closed form.

    The more recent researches, however, are not directly applicable to
Plateau's experiments, for when the densities of the two immiscible liquids
are taken to be equal, a gradient in the speed of rotation should be maintained
across the interface in order for the changes in the relative equilibrium
configurations to be observable. Accordingly, an extension of these analyses
was sought in which, for generality, the densities and speeds of rotation of
the two liquids were assumed to be different. The liquids are otherwise
homogeneous, incompressible, and rotating at constant speeds so that viscosity
effects do not influence the results. It then follows that the governing
parameter is

$$\Omega = \frac{(\rho_1 \omega_1^2 - \rho_2 \omega_2^2) a^3}{8T} , \quad \frac{\rho_1}{\rho_2} \neq \left(\frac{\omega_2}{\omega_1}\right)^2$$

where T is interfacial tension, ρ and ω denote respectively the density and speed of rotation of the liquids, the subscripts 1 and 2 stand for the immersed liquid and surrounding liquid, respectively, and 'a' is a characteristic length. When $\Omega > 0$, the immersed fluid behaves like a "drop", i.e., it flattens at the poles as the speed ω_1 is increased relative to ω_2. When $\Omega < 0$, the immersed fluid behaves like a 'bubble', i.e., it elongates at the poles as the speed ω_2 is increased relative to ω_1. As long as the interface intersects the axis of rotation a closed form solution in terms of elliptic integrals is still possible. As soon as a ring is formed, however, the solution in terms of an hyperelliptic integral should be used and its evaluation performed through expansion in series. Special cases in which the latter solution can possibly be reduced to tabulated elliptic integrals is under consideration.

4. **Fluid Response of a Wetting Liquid Enclosed in a Rotating Cylindrical Tank in a Zero-G Environment and Subjected to a Small Transverse Disturbance Force:**

A cylindrical tank rotating about its symmetry axis with constant angular velocity is partially filled with a wetting liquid. The vessel is placed in a zero-g environment. The liquid is assumed to execute a rigid body rotation. Since we are dealing with a wetting fluid, a vapor pocket will be formed, which is located inside the tank surrounded by liquid. The liquid-vapor interface in a state of equilibrium will be a surface of revolution about the axis of rotation (elongated ellipsoid). If the system is now subjected to a steady, transverse force field, so that the interface is no longer axially symmetric, a secondary rotational flow will be induced in the bulk of the fluid.

The investigation of this problem has been attacked by means of a linearized analysis of the equations which describe the motion of the secondary flow. The results of this study will include: (a) the equilibrium configuration of the perturbed system; (b) the amount of secondary circulation induced in the liquid body; (c) the determination of critical values of certain parameters (e.g., Bond number) at which the vapor cavity will tend to collapse; (d) the extension of the analysis to the case of oscillatory and impulse disturbances.

5. **Hydroelastic Solution of the Sloshing of a Liquid with a Free Surface in a Cylindrical Tank having a Flexible Bottom:**

The motion (coupled oscillations) of a non-wetting liquid enclosed in a flexible vessel (cylindrical tank with rigid walls and flexible bottom)

is studied for the cases in which the bottom is assumed to be (a) a membrane and (b) a thin elastic plate. If this system is placed in a low gravitational field, the surface tension force at the free surface (liquid-vapor interface) is an important factor in the analysis. Small oscillations of the fluid about the static equibibrium configuration, which can be determined by employing the principle of minimum energy and thus is considered to be known, are analyzed in order to study the longitudinal motion of the liquid which seems to couple sufficiently with that of the structure to produce noticeable responses. The coupled boundary value problem of the liquid and the flexible bottom are studied for both the axisymmetric and asymmetric cases.

The complex interaction problem of structure and fluid can be avoided by assuming that the structure has known displacements (functions of time and space) and then solving for the flow field. Although this treatment discloses the properties of the fluid field, it does not permit the determination of the response of the structure to external forces without further analysis.

The latter case is under investigation also in order to allow for an approximate treatment of a container with flexible (breathing) walls, but rigid bottom. To obtain the response of the structure it is, of course, necessary to solve the equations of fluid flow simultaneously with appropriate equations describing the behavior of the structure (e.g., thin shell theory). This will be done at a later date.

6. Response of an Incompressible Liquid in a Cylindrical Vessel Due to Single Pulse Excitation:

During flight in a near-zero gravitational environment, a space vehicle is subjected to control disturbances which in certain cases are of single pulse nature. These disturbances make the liquid in the container of the vehicle slosh. Assuming that the equilibrium configuration under no disturbing forces is known, we will investigate the response to rectangular and triangular single pulse inputs of (a) a non-wetting liquid with free fluid surface and (b) a wetting liquid.

7. Budget:

	To date Expenditures	Anticipated Expenditures
Salaries	$ 4,685.56	$ 534.00
Expense	41.63	103.00
TOTAL	$ 4,727.19	$ 637.00

PROJECT A10:   STUDY OF GRAIN BOUNDARY PROPERTIES AND THE ROLE OF MECHANICAL
STRESSES IN THE PROCESS OF HIGH-TEMPERATURE OXIDATION

1. Department: Metallurgical and Materials Engineering

2. Principal Investigator: F. N. Rhines

Graduate Research Assistant: J. E. Lemons

3. Introduction:

Phase I of this research, dealing with the role of mechanical stresses
in the process of high-temperature oxidation, has been completed and a
paper is being written for formal presentation. Phase II of the study, deal-
ing with the mechanical properties of grain boundaries, has been started and
some results are given in this report.

4. Phase I:

The oxidation of nickel at high temperature is characterized by
oxide growth on both the exposed and the lateral (grain boundary) faces
of all NiO crystals that are in direct contact with metallic Ni. This
results in a thickening of the oxide and also in a lateral growth, which
creates a compressive stress parallel with the oxide-metal interface.
This stress, which was found to exceed 15,000 psi, tends to deform the
underlying metal and also causes plastic flow in the growing oxide film,
thus inducing recrystallization in a zone adjacent to the metal. When new
oxide grains intervene between the original oxide grains and the metal, the
locus of principal oxide growth shifts to a region close to the metal
surface, while the rate of oxide thickening changes from a parabolic to a
linear (slower) dependence upon time. Required for this mode of oxidation
are the following factors: (1) Ni diffuses only through the NiO lattice
from metallic Ni to the first surface, be it NiO-air, or an NiO-NiO grain
boundary; (2) Ni does not diffuse along, or across, NiO-NiO grain boundaries;
(3) Oxygen diffuses along NiO-NiO grain boundaries; (4) Oxygen does not
diffuse through the NiO crystal; (5) NiO is capable of plastic deformation,
including grain boundary shearing.

5. Phase II:

Grain boundary strengthening in bulk specimens of recrystallized
alpha brass is being investigated as a function of solute concentration
and temperature.

Boundary strengthening is measured by means of several testing
procedures; e.g., Brinell hardness, tensile strength and compressive
strength. These tests are applied to a series of comparable specimens
of variable, but known, boundary area. The boundary area (cm^2/cm^3) is
being determined by a method of intercept counting. Testing has thus far
been limited to Brinell hardness while the tensile and compressive test
specimens are being produced.

Brinell Hardness Number (BHN) is found to be a linear function of
boundary area for the complete alpha brass series (95-65 ^{W}/o Cu). The
slope of the BHN-boundary area relation changes with composition, showing
a maximum at approximately 30 ^{W}/o zinc. This maximum can possibly be
interpreted in terms of grain boundary energy. Preliminary investigation
of mercury embrittlement along grain boundaries shows the same trend as seen
in the BHN-boundary area slope change, indicating that high energy boundaries
block shear movement much more effectively than do low energy boundaries.
More extensive studies of absolute grain boundary energies are now being
considered.

The BHN-boundary area slope changes slightly with temperature.
Temperatures under consideration are 77, 298, 573 and 873°K. The 77,
298 and 573°K studies are now complete. These temperatures were so
selected as to include the recovery and recrystallization range for all
alloys. Since this investigation is incomplete, no firm conclusions can
be drawn at this time.

6. **Budget:**

	Expenditures To Date	Anticipated Expenditures
Salaries	$ 2,282.75	$ 3,107.25
Expenses	411.90	288.10
Equipment	-0-	600.00
TOTAL	$ 2,704.65	$ 3,995.35

PROJECT A11:   MECHANISM OF FRACTURE OF HAFNIUM-ZIRCONIUM ALLOYS

1. **Department:** Metallurgical and Materials Engineering

2. **Principal Investigator:** R. E. Reed-Hill

   Graduate Research Assistant: D. H. Baldwin

3. **Activity to Date:**

X-ray diffraction techniques have been used to measure the lattice
parameters of the zirconium-oxygen alloys. Zirconium lattice parameters
vary strongly with oxygen, so that a measurement of moderate precision is
sufficient to determine oxygen concentration. The correlation between
lattice parameters and oxygen content has been determined by earlier invest-
igators.

A method for growing large grains (up to 2 mm) in zirconium has been
developed. It was found that exaggerated grain growth occurs in fine grained,

highly textured zirconium when it is strained 15 to 20% and annealed at 800°C. The as-received plate was cold rolled 80% and recrystallized 10 minutes at 600°C to produce the fine grained, textured starting material. Large grains were desired to facilitate orientation determinations by x-ray diffraction and two-surface slip trace analysis after deformation.

The fracture of a low oxygen (1.8%) alloy has been studied extensively. The specimen consisted of a flat strip 0.072 x 0.200 x 3 inches. A "neck" was milled into the center of the specimen as a deliberate stress raiser to localize the critical strain for the exaggerated grain growth mentioned above. After critical straining and annealing, only large grains appeared in the neck region. This sample was then oxidized at 600°C and subsequently annealed in high vacuum to dissolve the oxide, the resultant oxygen concentration in the bulk being 1.8% as measured by hardness. The surfaces were polished prior to tensile deformation.

The load-time curve indicated that the specimen yielded at 45,400 psi. With subsequent deformation, necking occurred, as in any ductile material, and the load began to decrease. At a nominal stress of 66,000 psi a click was heard and a corresponding 1,300 psi load drop was observed. The specimen was unloaded for microscopic examination, which revealed a crack in one crystal at the neck. A two-surface analysis of this particular rupture indicated that it occurred on approximately a [10$\bar{1}$2] plane. Following direct observation of the extent of this crack on two surfaces of the specimen, straining was continued until the remaining sound material fractured at a nominal stress of 42,600 psi or a true stress of approximately 81,600 psi.

The large grains through which the rupture passed were oriented with Laue photographs, where possible. The results of this survey indicate that the coarse grains show a very strong texture, with (0001) nearly parallel to the rolling plane. The total fracture surface passed through six visible grains. The original crack mentioned above apparently traversed completely through one of these grains to initiate failure. Four of the remaining five grains appear to have failed by simple shearing off on [10$\bar{1}$0] planes. The sixth grain is not readily accessible for examination, but the information available suggests failure on some non-prism plane, similar to the crack in the first crystal.

The Laue photographs indicate, by spot asterism, that the grains themselves in most cases have bent about an axis perpendicular to the (0002) plane. This is in agreement with the observation of only [10$\bar{1}$0] slip traces. Also, it is interesting to note that in the four grains where final rupture occurred by shearing along [10$\bar{1}$0] planes, bending in each case brought the prism planes into a 45° alignment with the stress axis, i.e., positions of maximum shear stress.

4. Areas currently being pursued:

About 100 small tensile specimens are being prepared from high purity zirconium plate. It is planned to use these to obtain mechanical properties as a function of oxygen content, test temperature and strain rate.

Additional large-grained specimens are being prepared with higher oxygen contents.

It is also planned to examine fracture surfaces with the electron microscope, using a replica technique.

5. __Budget:__

	Expenditures To Date	Expenditures Anticipated
Salaries	$ 2,167.20	$ 2,092.80
Expenses	596.68	2,383.32
Equipment	-0-	700.00
TOTAL	$ 2,763.88	$ 5,176.12

PROJECT A12:   LOW TEMPERATURE INTERGRANULAR FRACTURE OF MAGNESIUM

1. __Department:__ Metallurgical and Materials Engineering

2. __Principal Investigator:__ R. E. Reed-Hill

   __Graduate Research Assistant:__ W. H. Hartt, III

3. __Activity to Date:__

Studies on the room temperature deformation and fracture properties of high-purity polycrystalline magnesium have been continued with special emphasis on the role of $[30\bar{3}4]$ twinning. The primary texture in fabricated magnesium is that in which the basal plane is aligned parallel to the specimen axis. Since basal slip is the only prominent deformation mode available at room temperature, a very low elongation-to-fracture value results. The $[30\bar{3}4]$ or second order $[10\bar{1}1]$ - $[10\bar{1}2]$ twins are interesting and unique in a number of ways: first, fractures often occur by crack formation at these twins; and secondly, large amounts of deformation may occur in these twins while the specimen is still brittle macroscopically.

Recent studies of the second order twins have been conducted by examining in the electron microscope replicas taken from deformed specimens. Replicas were obtained by using the double replica, cellulose acetate-carbon technique. These studies have revealed that the internal structure of the twins is often so heavily distorted that the deformation is best described as turbulent flow. In such twins no distinct slip traces remain; and cracks, which are easily viewed by this technique, appear to progress along the twin boundary.

Slip traces can, however, be seen in twins which have undergone less deformation, but the orientation of these traces is presently not accounted

for in terms of the predicted lattice reorientation. Also seen in twins of this type is crack initiation, which begins through a series of pores opening up at the twin boundaries; these are assumed to interconnect, giving rise to a postage-stamp type of failure.

Grain boundary offset has been observed in magnesium specimens, and replicas have revealed that the associated areas have much the same appearance as the turbulent flow observed in the second order twins. Cracking in such regions was observed, not at the grain boundary, but at the edge of the distorted, offset region.

It is hoped that the present observations can be confirmed and a full understanding of second order twins obtained. It is also desired to view these twins by transmission electron microscopy with selected-area diffraction in order to observe the dislocation structures and to determine orientation relationships.

4. Budget:

	Expenditures To Date	Expenditures Anticipated
Salaries	$ 2,167.20	$ 2,192.80
Expenses	339.34	1,140.66
Equipment	-0-	700.00
TOTAL	$ 2,506.54	$ 4,033.46

PROJECT A13:   A STUDY OF THE FLUID STATES OF MATTER

1. Department: Physics and Astronomy

2. Principal Investigator: A. A. Broyles

   Co-Investigator: C. F. Hooper

3. Technical Progress:

It is our purpose to develop methods of computing the equations of state of matter in the fluid state, including plasmas. We believe that our methods will be particularly useful when applied to physical situations not amenable to laboratory investigation. The studies of stellar atmospheres and nuclear bomb explosions serve as illustrations. We are developing and testing these methods by computing equations of state and related quantities, such as radial distribution functions, for fluids now available to physical experiment. Since the shape of spectral lines can, in principle, be used to determine the density and temperature of the radiating material, we are devoting time to computing these shapes theoretically.

We have, in the past, obtained thermodynamic quantities and x-ray and neutron diffraction intensities from assumed interatomic potentials and compared them with experiment. We have also inverted these calculations to obtain the potential directly from the experimental diffraction data. This has been of considerable interest to those computing interatomic potentials using the Born-Oppenheimer approximation. Because of the incompleteness of the data, our potentials have shown spurious structure. We have succeeded in removing this structure by smoothing techniques that we have developed, and we have presented preliminary results.[1]

We have developed methods for treating quantum systems by approximating the Slater sum (diagonal density matrix) as a classical Boltzmann factor for a system with a pairwise effective potential. As a test of this procedure, we have determined these effective potentials for ideal gases obeying both Fermi statistics and Bose statistics (above the λ point). The internal energy has been computed from this effective potential, and very favorable comparisons have been obtained with the exact mode energy. We are now pushing ahead to compute the equation of state of He^4 above the λ point for comparison with experimental data, and to compute the ground-state energy of the electron gas for comparison with high density theoretical calculations performed in the past for this system.

Improved methods for computing radial distribution functions for equations of state of classical systems have now been published. [2]

A major contribution to spectral line broadening in plasmas is due to the Stark effect of ions near to the radiating atom. We have, up to now, concentrated on the determination of the probability distribution of these electric fields (the microfield distribution). The theory developed under this grant is designed to eliminate the often questionable assumptions made necessary by the use of particle correlation functions. We are currently able to calculate the microfield distributions and will soon go into production of them for a large range of parameters. We are making comparisons with microfields computed by Monte Carlo methods. Once completed the theoretical results will be applied to the spectral line broadening theory.

4. Publications Since the Last Report:

1. "Interatomic Potential of Krypton," A. A. Broyles and A. A. Khan, Bulletin of the American Physical Society, 10, 458 (1965).

2. "Approximate Methods for Obtaining Radial Distribution Functions of Fluids," D. D. Carley and F. Lado, The Physical Review 137, A42 (1965).

5. Budget:

	Expended To Date	Anticipated Expenditure
Salaries	$ 6,148.08	$ 6,390.00
Expenses	366.94	8,594.98
TOTAL	$ 6,515.02	$ 8,594.98

PROJECT A15: MOLECULAR BEAM INVESTIGATIONS OF SURFACE REACTIONS

1. **Department**: Chemistry

2. **Principal Investigator**: E. E. Muschlitz, Jr.

3. **Progress**:

The molecular beam technique has a number of distinct advantages as applied to the problem of surface reactions. The surface under investigation may be oriented with respect to the direction of the incident molecules, the angular distribution of the particles leaving a hot surface may be studied, and the identity of any active species produced (excited molecules, atoms, or free radicals) may be determined before they are destroyed by gas phase or wall collisions. Very few studies along these lines have so far been attempted. Yet the information which may be obtained is of considerable value with respect to a number of practical problems arising in the space program, particularly the problem of re-entry.

The apparatus for this research will be constructed inside a large vacuum chamber approximately four feet in diameter and 2 feet high. The surface to be investigated will be mounted in the form of a ribbon in the center of this chamber and heated electrically to temperatures in the range 1000-2500°K. Molecular beams will be incident on the surface. Molecules and radicals leaving the surface will be identified, after ionization by electron impact, by using a four-pole mass spectrometer, which will be mounted so that it can be rotated about the surface. Thus, studies of the formation of radicals as a function of angle of incidence of the molecular beam, the angle at which they leave the surface, and the temperature of the surface may be made. Prior studies by Smith and Fite (J. Chem. Phys. **37**, 898 (1962)) have shown that when a beam of hydrogen molecules is incident on a hot tungsten surface the hydrogen atoms produced come off with a cosine distribution. It is planned to reinvestigate this system and to extend the measurements to D_2 and HD. In the case of HD molecules incident on the surface, it will be very interesting to obtain the relative production of H_2 and D_2 as a function of angle. The measurements will eventually be extended to oxygen and to nitrous and nitric oxides as well.

This research had not progressed beyond the acquisition of major items of equipment until last October, when Dr. J. T. Scott joined the project as a postdoctoral fellow. As of May 1, Mr. R. N. Coltharp also joined the project as a one-third time graduate assistant, and the apparatus is now well under construction. The vacuum chamber has been received and is now in the process of being set up. The mass spectrometer has been purchased outright and the design for the mechanism for rotating it within the vacuum chamber is well under way. Construction of the interior parts will be started shortly, and it is expected that the system will be under vacuum within the next few months. It is hoped that preliminary experiments will be completed by the end of the summer.

4. **Budget**:

As of April 16 expenditures for the period beginning 10/31/64 have been as follows:

Part-time machinist	$ 1,900
Postdoctoral fellow	3,300
Permanent equipment	12,860
Expendable equipment and supplies	952
Total	$19,012

Anticipated expenditures for the remainder of the current grant period are:

Part-time machinist	$ 1,900
Postdoctoral fellow	4,200
1/3-time graduate assistant	900
Permanent equipment	2,400
Expendable equipment and supplies	2,500
Total	$11,900

PROJECT A16: COLLISIONS OF MONOENERGETIC ELECTRONS WITH ATOMS AND MOLECULES

1. __Department__: Physics and Astronomy

2. __Principal Investigators__: T. L. Bailey and B. S. Thomas

3. __Background and Status as of November 1, 1964__:

The objective of this project has been to initiate experimental studies of collisions of electrons with neutral gaseous atoms and molecules and with positive ions, using crossed beam techniques. Construction of an apparatus for these electron experiments was essentially complete as of November 1, 1964. This apparatus will also be used in studies of low energy ion-neutral collisions; this phase of the research has received concurrent support through a grant from AFOSR. The essential parts of the apparatus are: (1) an ion gun, which produces a mass and velocity selected ion beam; (2) a collision region; and (3) a product ion analyzer and detector system. In its present configuration, the apparatus is suitable for either ion-electron collision studies or ion-neutral collison studies. The product ion system consists of a 127° cylindrical condenser velocity analyzer (identical with that used in the primary gun), followed by a quadrupole field mass filter and a Bendix electron multiplier. The entire product ion system can be rotated about the collision region through an angular range of $-5^\circ \lesssim \theta \lesssim 90^\circ$ with respect to the primary ion beam. The flux of product ions (arising from electron-ion collisions or from ion-neutral collisions) emerging from the collision region at a given angle θ is measured by counting the output pulses from the multiplier.

4. __Technical Accomplishments__ (November 1, 1964-April 30, 1965):

The apparatus was tested thoroughly during this period, and was found to perform well. After completion of the tests, preliminary studies of ion-neutral collisions were begun. These initial studies were concerned primarily with collisions of Ar^+ and Ar^{++} ions with D_2 molecules. The

reaction: $Ar^+ + D_2 = ArD^+ + D$ has been studied in detail, over the primary ion kinetic energy range of 1.5 to 40 eV. Angular distributions of the product ArD^+ are sharply peaked in the primary beam direction, as required by energy-momentum conservation. The kinetic energy distributions of ArD^+, at given scattering angles, are also sharply peaked and show no evidence of contributions of excited internal states of Ar^+ or ArD^+ to the reaction. Comparison of the maximum energies of the primary Ar^+ and product ArD^+, taken at zero scattering angle and at several primary ion energies, gives a Q value for this reaction of $Q = 0.00 \pm 0.05$ eV. Assuming that the reactants and products are all in their ground states, this gives a value for the dissociation energy of ArD^+ of 4.51 ± 0.05 eV. In collisions of Ar^{++} with D_2, the product Ar^+ was observed. The Ar^+ ions were found to be strongly peaked in the forward direction, with quite narrow energy distributions. The maximum kinetic energies of Ar^+ products were found to exceed the kinetic energies of primary Ar^{++} ions. The observations suggest that the Ar^+ is produced by $Ar^{++} + D_2 = Ar^+ + (D_2^+)^*$, followed by dissociation: $(D_2^+)^* = D^+ + D$. On this assumption, the measured Q for the first step was $Q = +2.20$ eV., which implies an approximately vertical transition from the ground state of D_2, to the repulsive $^2\Sigma_u$ state of D_2^+. D^+ or D_2^+ were not observed, but if these ions were formed with broad distributions in angle, their product intensities would have been below the detectability limit of the apparatus.

A paper based on the preceding work, entitled "Angular and Energetic Studies of Reactive Ion-Neutral Collisions," by T. L. Bailey, R. L. Champion, L. D. Doverspike, and J. J. Leventhal, will be presented at the International Conference on the Physics of Electronic and Atomic Collisions, Quebec (August, 1965).

5. <u>Budget</u>:

	Original Budget	Expended (11/1/64-4/30/65)	Anticipated Expenditures (5/1/65-10/31/65)
Salaries	$7,975	$1,800 (a)	$ 5,175 (a,b,c)
Expense	3,763	2,491	1,772
Capital Outlay	6,262	3,096	3,666
TOTALS	$18,000	$7,387	$10,613

(a) One half-time graduate research assistant (R. L. Champion) 11/1/64 to 10/31/65.
(b) Two half-time graduate research assistants (L. D. Doverspike and J. J. Leventhal), 7/1/65 to 9/31/65.
(c) One full-time graduate research assistant (Mr. M. J. Wynn), 5/1/65 to 6/30/65.

PROJECT A17: NUCLEAR PROPULSION PROBLEMS

1. <u>Department</u>: Nuclear Engineering

2. <u>Principal Investigator</u>: Robert E. Uhrig

3. Progress:

Work under Project A-17 proceeded along three separate paths. In the first of these Mr. Robert Kemerait, a one-third-time Graduate Assistant, worked on the formulations of appropriate mathematical models to represent a nuclear rocket system on an analog computer, and undertook to simplify this system to one which can be represented on the present analog computing system. His model includes the reactor kinetics equations, the gas dynamic equations for flow through a choked nozzle, temperature feed-back effects, hydrogen coefficient effects, xenon build-up, etc.

The second project, which was undertaken by J. T. Humphries as the initiation of a Ph.D. dissertation project, is the study of a model reference adaptive control system for nuclear rocket propulsion systems. He will utilize the simulation of the nuclear rocket system carried out by Mr. Kemerait and attempt to delineate the dynamic behavior and characteristics when an adaptive type control system is used. A model reference-type adaptive system has been chosen since it appears to be the one which will be most advantageous from a performance standpoint. However, the problem is extremely non-linear and not susceptible to a rigorous analysis. Hence, it is necessary to proceed on the basis of a combination of analysis and simulation. Mr. Humphries' efforts have been concentrated on the adaptive control system itself, rather than on the nuclear rocket system. The two will be combined later. The preliminary study is being pursued to gain insight into the basic concepts of operation of the model reference adaptive control technique. In this scheme, the controller compares the output of a "system" with that of a "reference model," and "adapts" so that the input response of the controller-system combination matches that of the reference model. Included in this investigation have been: (1) choice of the reference model, (2) design of the adjusting mechanism, and (3) choice of the adjustment method.

In the simulation, both system and reference model are of second order. The model is explicit; i.e., it uses a priori knowledge of the system. Partial derivative methods are used in the adjustment mechanism, and the open loop gain is the adjustable, i.e., adaptive, parameter. Response of the controller-system to a variety of command inputs as a function of offset open loop gain is under continuing investigation.

The third aspect of this program deals with neutron flux state changes in a nuclear rocket system by the use of Pontryagin's maximum principle. In this project the object is to obtain the optimum performance under different constraint--i.e., minimum time, minimum fuel and minimum energy. This work has been described previously and it is progressing nicely.

A considerable amount of time was also spent studying the various possible modifications of the Applied Dynamics AD-80 analog computer and its coupling to a digital computer to make a hybrid computation system. As a result of this study, a large number of components were ordered for the Applied Dynamics system, including electronic switches, track-and-hold units, electronic comparators and a matrix-type address selector system. Also, an order was placed for an IBM-1800 digital computer, which will constitute

the digital portion of the hybrid system. Delivery on the digital computer is not scheduled until early in 1966, and hence it will be necessary to proceed with the analog system and to utilize operational amplifiers in the track-and-hold mode for storing values of analog variables. The electronic switches and comparators will allow a great deal of digital logic to be carried out on the analog system.

During the months of November and December, Messrs. Kemerait and Saluja were supported from this grant. However, the financial situation was such that it was necessary to divert funds from the salary items to the purchase of equipment for the hybrid computational system. Permission to do this was obtained, and all the remaining funds were committed to the purchase of the IBM-1800 digital computer. Hence, there are no funds remaining for this fiscal year. However, Messrs. Kemerait and Saluja have continued work on this project and have been paid from departmental funds. In addition, Mr. Humphries is an Air Force captain on active duty while going to school, and will continue to work on this project. Drs. M. J. Ohanian and R. E. Uhrig devoted substantial fractions of their time to this project, as well as Dr. A. P. Sage of the Electrical Engineering department.

A proposal has been submitted to the National Aeronautics and Space Administration by R. E. Uhrig and A. P. Sage, requesting continued support of this project. However, we have received no indication as to whether it will be funded, and, if so, when. Unfortunately, the only possible source of such funds within the NASA organization is the Space Nuclear Propulsion Office, and this particular office has been known to be more interested in hardware than in research. We are, however, encouraged by indirect word from acquaintances at Los Alamos that the preliminary technical review of this project is favorable.

PROJECT A19: PHOTOELECTRIC PHOTOMETRY OF VARIABLE STARS

1. **Department**: Physics and Astronomy

2. **Principal Investigator**: Kwan-Yu Chen

3. **Progress**:

During the first two months of this period, electronic equipment was tested, and trial observations were made with the 12.5-inch reflecting telescope and the assembled equipment, which includes the photometer head (UBV system), DC amplifier, strip-chart recorder, and power supplies. The equipment is located at the University of Florida Radio Observatory at Gainesville, Florida. Actual observations began in late January. Data were taken for determining atmospheric extinction coefficients for stars of different spectral types. Observations were also made of the eclipsing variable stars SX Cas, VV Ori, and 44i Boo. The observations of SX Cas have been designed to be a part of the international cooperative program for observing this star. Data on VV Ori and 44i Boo are being used as material for a master's thesis by Capt. Douglas Rekenthaler. These data are being reduced at the present time. Observations of selected eclipsing variable stars are being continued.

Commencing January 1, 1965, Mr. Roger Carr was appointed as a one-third-time research assistant on this project. His thesis for the degree of Master of Science will be on atmospheric extinction. A proposal has been prepared requesting support for this project from the National Science Foundation.

4. Budget:

The following table is a brief financial report for the project:

	Expenditures	Anticipated Expenditures
Salaries	$ 990	$4900
Operating Expenses	485	385
Capital Outlay	200	---
TOTAL	$1675	$5285

PROJECT A20: A THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE OPTIMUM EXPERIMENTAL CONDITIONS FOR ANALYSIS OF ATOMS BY ATOMIC EMISSION AND ATOMIC ABSORPTION FLAME SPECTROMETRY AND BY ATOMIC EMISSION ARC SPECTROMETRY

1. Department: Chemistry

2. Principal Investigator: James D. Winefordner

3. Summary of Research Accomplished:

Research apparatus to construct a plasma torch atomic and ionic absorption plasma spectrometer was ordered and assembled. The apparatus consists of a Spex Industry plasma torch, a Jarrell-Ash mechanical chopper, a Jarrell-Ash D. C. power supply, an Aminco monochromator, an Ealing optical bench, a 1P28 photomultiplier tube, and a Jarrell-Ash A. C. electrometer with a Digitec digital readout. This equipment is set up in a manner similar to atomic absorption flame spectrometers, and it has been completely calibrated but not yet completely tested for analytical measurements. These tests will be completed for a number of the transition metals, alkali metals, alkaline earths and soft metals in the months to follow.

Research on extended path atomic absorption flame spectrometry is now in progress. In this study, long quartz or ceramic tubes (10 to 50 cm. long) are being used to extend residence time of atoms in a beam of exciting radiation. The H_2/O_2 or C_2H_2/O_2 flame is directed into one end of the tube, and atomic absorption measurements are taken while using a continuous source of excitation (a tungsten filament lamp). Using this technique, it has been possible to detect one part-per-billion of sodium and ten parts-per-billion of calcium. Other elements are being studied by this same method, and a limit-of-detectability theory is being derived according to the approach of Winefordner and Vickers (Anal. 36, 1938 and 1947 (1964)).

More recently, a Fortran computer program has been prepared which allows

damping constants, collisional half-widths, collisional cross-sections,
Doppler half-widths and total line half-widths to be calculated for a
range of flame types and temperatures, and for a number of different spec-
tral lines of a large number of atoms. These values are then compared with
values of the same parameters measured using the well-known total-absorption
technique of Hinnov (J. Opt. Soc. Am. $\underline{47}$, 151 (1947)). The measurements
are taken for the case when the atoms are introduced as a variety of com-
pounds into analytical flames, e.g., H_2/O_2, H_2/air, and C_2H_2/O_2. Results
are extremely encouraging so far, and should be of great use in the esti-
mation of limiting detectable concentrations in atomic emission and atomic
absorption flame spectrometry. In addition, these results should be of
interest in the prediction of the growth curves that are of such importance
in astrophysics and analytical working curves.

During the next six months it is expected that several papers will be
written concerning the research described above.

4. <u>Budget</u>:

<u>Financial Expenditures, November 1, 1964 to May 1, 1965</u>

<u>Personnel</u>

M. Parsons (Half-time Grad. Assistant four months)	$ 1,200.00
W. McGee (Half-time Grad. Assistant four months)	1,200.00
<u>Non-Expendable Equipment</u>	2,958.80*
<u>Expendable Equipment**</u>	1,276.43*

<u>Anticipated Expenditures, May 1, 1965 to November 1, 1965</u>

<u>Personnel</u>

M. Parsons (Half-time Grad. Assistant six months)	$ 1,800.00
W. McGee (Half-time Grad. Assistant six months)	1,800.00
<u>Non-Expendable Equipment</u>	75.32*
<u>Expendable Equipment</u>	41.20*
ESTIMATED TOTAL	$10,400.00

*Because of large initial costs for non-expendable and expendable
equipment, most of the funds other than for personnel have been depleted.
However, the remaining funds should be sufficient for the remaining six
months.

**Itemized Listing of Non-expendable Equipment

Jarrell-Ash Gas Regulator Unit	$ 295.00
Vacuum Pump	107.00
Princeton low noise preamplifier and lock-in amplifier	1,666.45
Keithley electrometer, probe and power supply	982.53

PROJECT A21: SELF-CONSISTENT FIELD SOLUTIONS FOR NUCLEI

1. <u>Department</u>: Physics & Astronomy

2. <u>Principal Investigator</u>: A. E. S. Green

3. <u>Progress</u>:

The work accomplished to date under this project has been highly re-
warding, especially considering the very modest nature of the expenditures
($1500). We have established the fact that the theoretical work on meson
theory of nuclear forces carried out by the principal investigator in 1949
contains the same pseudoscalar, vector and scalar mesons utilized by
several groups during the past year. Inserting recently-discovered meson
masses into our old theoretical expressions, we have derived a set of
nucleon-nucleon potentials which agree favorably with phenomenological
nucleon-nucleon potentials recently inferred from nucleon-nucleon data. Our
work (see March 8 Phys. Rev. Letters) differed in two respects from the
recent work of Bryan and Scott: (1) They did not have velocity-dependent
terms in their central potentials; (2) they utilize a 500 MeV scalar meson,
whereas we use a meson comparable in mass to the ω meson (i.e. $\sim$ 700 MeV).
The former difference has been resolved, in that they have found the missing
velocity-dependent terms, which agree identically with our own. Recent ex-
perimental evidence on the existence of a scalar meson now faovrs the 700
MeV value required in our theory.

The Office of Scientific Research has recently awarded a substantial
grant for the continuation and development of this theoretical program.
Thus we will require no further support from the NASA Institutional Grant
for this research. We anticipate that the "seed corn" provided by the
Institutional Grant will blossom and yield a rich harvest of fundamental
knowledge.

4. <u>Publications</u>:

"Velocity Dependent Nucleon-Nucleon Potential," A.E.S. Green & R. D.
Sharma, Phys. Rev. Letters, <u>14</u> 380 (1965).

"Mesonic Nucleon-Nucleon Potential," Paper presented at American Physi-
cal Society, Washington, D. C. April 26-29, 1965.

5. <u>Budget</u>:

The $1200 in direct funds used in this program have been used for (1)
computing expense; (2) Publication expense; and (3) traveling expense.

PROJECT A22:   THE HYDROTHERMODYNAMICS OF A PLANE LAMINAR JET

1.   Department: Aerospace Engineering

2.   Principal Investigator: Knox Millsaps

3.   Progress:

      One of the classical problems in fluid mechanics is the dynamics of
a plane laminar jet; i.e., the fluid motion produced by the application
of a undirectional momentum flux along a line. The physics of the problem
was treated by the use of boundary layer theory by Schlichting (his
mathematics are incorrect), and the pertinent mathematical problem was
solved by Bickley. The associated heat transfer problem was treated in
an approximate manner by Yih. The classic attempt by Andrade to verify
the theoretical results of Bickley by experimental measurements yielded
only "tolerably good" results.

      The objectives of the present study, which has been pursued for the
three-month period since 1 February 1965, are: (1) to verify the
theoretical results of Bickley; (2) to treat the associated heat trans-
fer problem in an exact manner; and (3) to measure the thermal distribution
in a plane laminar jet. The results are: (1) a manuscript containing
the results for the exact solution of the heat transfer problem is being
prepared; (2) a flow tank with a slit has been constructed, and the
first photographs indicate that a plane laminar jet of 7 to 11 inches
length and 6 inches width has been achieved; and (3) micro-thermocouples
are being constructed and calibrated against certified Pt, Pt-Rh thermo-
couples.

      Two graduate students and one undergraduate assistant have been
working on this task.

4.   Budget:

   Expenditures:

Salaries	$ 112.50
Expenses	90.07
Capital Outlay	686.00
TOTAL	$ 888.57

   Projected Expenses:

Salaries	$ 3,162.50
Expenses	773.82
Capital Outlay	110.50
TOTAL	$ 4,056.82